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CHAPTER 1

Intracardiac Echocardiography: Basic Concepts

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Introduction

Intracardiac echocardiography (ICE), also termed intracardiac ultrasound catheter imaging, allows visualization of the heart from within the cardiac chambers or from within the great vessels. Catheter-based ICE has advanced from devices bearing single-element transducers and M-mode transducers [1,2] to the current technology, which allows for higher resolution two-dimensional imaging with pulsed/continuous-wave Doppler and color flow evaluation of blood vessels and intracardiac structures.

Historical developments

Over the past 15 years, transducer miniaturization and advances in microelectric and piezoelectric crystal technology have allowed ICE to become an invaluable tool for cardiac assessment. No other technology allows for such superb temporal and spatial resolution through opaque blood [3–7]. In the late 1970s and early 1980s, real-time M-mode echocardiography was tested for intracardiac imaging [8,9]. In the 1990s, modified transesophageal transducers with low frequency (5 or 7 MHz) were used as ultrasound catheters for intracardiac imaging research in animal models but were not in clinical use due to the large size (24–30 Fr) of the transducer [5,6,10,11]. A higher frequency (20 MHz) intravascular ultrasound catheter was available for intracardiac imaging in 1990 [12] but was suboptimal for imaging of cardiac structures due to its diminished tissue penetration. One of the initial limitations of this growing technology was the large size of the lower frequency ICE catheters. Clinical usage of these devices was limited until a 12.5 MHz (6 Fr, mechanical system, Boston Scientific Co., Watertown, MA) and a 10 MHz (10 Fr, mechanical system, Cardiovascular Imaging System, Sunnyvale, CA) ultrasound catheter were developed in the early 1990s. Clinical acceptance of these lower frequency ultrasound catheter transducers was rapid in that detailed cardiac anatomy and function could be easily defined [13–15]. The clinical efficacy and safety of ICE for diagnosis of cardiac structure and function, for guidance of radiofrequency catheter ablation, and for transseptal catheterization have been extensively described [13–20]. With further lowering of ultrasound frequency, ICE with 9 MHz mechanical ultrasound catheter (9 Fr, Boston Scientific, Co., Watertown, MA) showed enhanced imaging capability with greater depth of imaging field compared with the 12.5 and 10 MHz catheters [21,22], but they still did not allow satisfactory imaging of the left heart from the right atrium or the right ventricle in adults or an enlarged heart. Recently, a new 5.5–10 MHz, 10 Fr, electronic phased-array ultrasound catheter with pulsed/continuous-wave Doppler and color flow imaging has been developed (AcuNav, Siemens Medical Solutions USA, Inc., Mountain View, CA). This device can be used for imaging of left heart structures, for visualization of mapping/ablation catheters, and for evaluation of pulmonary vein flow [23–25]. This ultrasound catheter has a flexible tip that provides for higher resolution and deeper penetration of the left side of the heart from the right atrium during interventional cardiac electrophysiologic procedures [24,26–27].

ICE in electrophysiology

During the past 20 years, interventional cardiac electrophysiology procedures have been performed almost exclusively under fluoroscopic guidance. Although this two-dimensional "silhouette" imaging provides a general representation of cardiac anatomy, it requires substantial experience to position the intracardiac catheter at a specific intracardiac target. However, with the increasing complexity of interventional electrophysiologic procedures, accurate imaging of intracardiac anatomic structures and interventional catheter devices has been required. So transesophageal echocardiography has been used as a major complement to fluoroscopy for imaging of intracardiac structures for guidance of interventional procedures, such as radiofrequency ablation and transseptal catheterization [28–32], and for assessing/monitoring the placement of transcatheter devices [33,34]. However, several disadvantages have limited its routine use during interventional procedures, including prolonged placement of the transesophageal transducer requiring heavy sedation and/or general anesthesia [30,35], the risk of vagal nerve stimulation that can be a potentially serious complication, and problems with inadequate orientation of transesophageal imaging planes for visualization of specific cardiac structures [10]. The new catheter-based ICE with mechanical radial imaging (9 MHz, 9 Fr) has demonstrated its utility for the safe and efficient guidance of transseptal catheterization [22]. For anatomically based ablation procedures in the right heart, this device can provide real-time guidance and monitoring of catheter location, its tissue contact and stability, and assessment of the targeted lesion, such as in sinus node ablation [36]. Electronically phased-array ICE can provide cardiac structural and functional imaging in more detail, especially for the left heart, which is comparable with transesophageal echocardiography, but without manipulation in a limited esophageal space. In contrast to the mechanical radial imaging catheter with a fixed ultrasound frequency and rigid tip, the electronic phased-array ICE catheter has variable ultrasonic frequency from 5.5 to 10 MHz and a deflectable tip, which provides greater detail and increased imaging depth, even in patients with cardiomegaly [24]. It also provides hemodynamic evaluation with Doppler and color flow imaging for the atria, ventricles, and the great vessels. An additional benefit of this newer technology is that the imaging catheter can remain in the right heart safely during the entire procedure with excellent patient tolerance [24]. The role of ICE during electrophysiologic procedures has been further demonstrated not only in guiding transseptal catheterization and assistance in catheter placement in the right heart, but also with assistance in placement of mapping/ablation catheters in the left heart, for instance in the pulmonary vein ostia or at the aortic valve cusps [37–39]. Rapid assessment of the pulmonary vein flow velocity and identification of hemodynamically significant stenosis can be made during pulmonary vein ablation procedures [25]. Instant detection of procedural complications, such as left atrial thrombus formation [40] and pericardial effusion, has allowed for early management strategies that limit adverse outcome [24]. More recently, ICE has been used to prevent esophageal damage during radiofrequency catheter ablation at the posterior left atrial wall adjacent to the esophagus by online assessment of lesion development [41,42]. Additionally, appropriate utilization of these powerful imaging tools has been accompanied by a reduction of fluoroscopic exposure time for both the patient and the physician which has been another benefit of ICE guidance [16,20,22].

Future directions

ICE heralds a novel era of catheter-based intracardiac ultrasound imaging technology. Additional improvement can be expected in the near future allowing multiplane and computer-reconstructed three-dimensional imaging [43,44], which will provide more rapid and efficient diagnosis, guidance, and monitoring. Although there are no reported complications directly related to the use of the ultrasound catheter, further refinement and miniaturization will expand its clinical applications and ease of use of ICE imaging in diagnostic and therapeutic interventional electrophysiologic procedures, especially for ventricular tachyarrhythmia ablation directed at the ventricular endo- and/or epicardium.

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